Responsible Research and Innovation in secondary school science classrooms

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Responsible Research and Innovation in secondary school science classrooms: experiences from the project Irresistible

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Abstract: Responsible Research and Innovation has become a core concept in many of the Horizon 2020 programs. In this article the concept of RRI is discussed in context of secondary education, and the interpretation used within the project 'Irresistible' is introduced. In the article several ways in which RRI can be incorporated in science classrooms are discussed, connected to the teaching of contemporary research taking place in universities as well as recent innovations coming from industry. The presented modules are designed in groups in which teachers work together with researchers, science educators and science center experts. As one of the educational approaches used in the modules, students created exhibits in which both the scientific content as well as the RRI concepts related to the content are demonstrated for the general public. These exhibits have been very successful as a learning tool.

Keywords: exhibits; formal learning; informal learning; Responsible Research and Innovation; science education; secondary school education; 2016 Spring ConfChem.

Introduction

This article focuses on the meanings of the concept of 'Responsible Research and Innovation' in the context of secondary education, as well as the approaches by which it can be introduced to students in science lessons.

Throughout the world ideas about the interaction between science and innovation with societal issues has become a subject of discussion. The United Nations for example has formulated sustainable development

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goals (https://sustainabledevelopment.un.org/?menu=1300) for science. Science should play an important role in attaining these 17 goals.

In Europe, the EU has looked for ways to meet the grand challenges. Grand challenges lay in the field of climate change, the aging population and energy security. These large scale and fundamental issues demand a coordinated effort of scientists. In the Lund declaration starting points for the Horizon 2020 program have been formulated, that will focus on working on these problems. An important factor in this framework is the coordination between different groups within society, so that a collective effort can be made to solve at least part of these problems.

Within the industrial society the idea of 'responsible care' (http://www.cefic.org/Responsible-Care/).

The Organization for the Prohibition of Chemical Weapons (OPCW) has formulated the 'The Hague Ethical guidelines' (https://www.opcw.org/special-sections/science-technology/the-hague-ethical-guidelines/) with a direct link to the 'Chemical Weapons Convention'. In the 'The Hague Ethical Guidelines' the link with individual accountability of chemists is made. Apart from the role in attaining the United Nations (UN) sustainable development goals, a broader role for chemists in promoting awareness, ethics, and science education is made. This more individual accountability is an essential part, which has also been promoted during the World Chemistry Leadership Meeting of IUPAC in Busan South Korea in August 2015 (www.iupac.org).

In April 2016 an article was published in Nature, contributing to the discussion on the position and the role of chemistry as a science [1]. Matlin et al. stress the need to re-imagine chemistry as they call it, with goals like *'being a science for the benefit of society'; 'being a sustainable science'; 'being an ethical science'*. One of their recommendations is about the relationship between chemistry practitioners and the general public. Open information about research that is carried out should be communicated openly with the general public.

The concept of 'Responsible Research and Innovation'

Within the EU this discussion has been going on for a while resulting in several framework programs.

Accordingly, the Framework programs about science and society have shifted in title from 'Science and Society' to 'Science in Society', and to 'Science with and for Society' indicating the change in perception within the EU about the role of science [2]. As a result, the concept of Responsible Research and Innovation have become more and more important. In Hillary Sutcliff's report [3] she identifies six key concepts in RRI (see Table 1):

In a later leaflet published by the EU in 2012 (http://ec.europa.eu/research/science-society/document_library/pdf_06/responsible-research-and-innovation-leaflet_en.pdf) six key issues are identified (see Table 1).

van Hoven [2] indicates:

> *"RRI refers to ways of proceeding in Research and Innovation that allow those who initiate and are involved in these processes at an early stage (A) to obtain relevant knowledge on the consequences of the outcomes of their actions and on the range of options open to them and (B) to effectively evaluate both outcomes and options in terms of ethical values (including, but not*

Table 1: Aspects of RRI as identified by Sutcliff and RRI leaflet.

Sutcliff	RRI leaflet
The deliberate focus of research and the products of innovation to achieve a social or environmental benefit	Engagement
The consistent, ongoing involvement of society, from beginning to end of the innovation process	Gender equality
Involvement of the public and non-governmental groups, who themselves are mindful of the public benefit	Science education
Assessing and effectively prioritizing social, ethical and environmental impacts, risks and opportunities, both now and in the future, alongside the technical and commercial	Ethics
Where oversight mechanisms are better able to anticipate and manage problems and opportunities and which are also able to adapt and respond quickly to changing knowledge and circumstances	Open access
Where openness and transparency are an integral component of the research and innovation process	Governance

limited to well-being, justice, equality, privacy, autonomy, safety, security, sustainability, accountability, democracy and efficiency) and (C) to use these considerations (under A and B) as functional requirements for design and development of new research, products and services."

von Schomberg [4] defines RRI as follows:

"Responsible Research and Innovation is a transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view to the (ethical) acceptability, sustainability and societal desirability of the innovation process and its marketable products (in order to allow a proper embedding of scientific and technological advances in our society)."

Both von Schomberg [4] and van Hoven [2] focus on the interaction between society and research and innovation. They demonstrate how important this interaction in order for innovations to succeed in society. An example is genetically modified food, which has not been accepted in Europe. Especially the steps formulated by van Hoven are not common as yet even though governments have started to formulate policies on this subject. In the Netherlands for example a new report was published indicating the view of the Dutch government on the future development of policies regarding scientific research, which are solidly based on these RRI concepts [5].

Within the project IRRESISTIBLE, we decided to use the six key issues from the leaflet as a starting point in the design of the activities within the project. They provide a more concrete set of issues that can be incorporated within educational activities. The underlining idea, that both research and innovation should be closely linked with society and the societal needs forms the background of the use of these six dimensions.

Table 2: The 6 dimensions of RRI (text taken from leaflet) used in the project.

1. Engagement
The first key to RRI is the engagement of all societal actors – researchers, industry, policymakers and civil society – and their joint participation in the research and innovation process, in accordance with the value of inclusiveness, as reflected in the Charter of Fundamental Rights of the European Union. A sound framework for excellence in research and innovation entails that the societal challenges are framed on the basis of widely representative social, economic and ethical concerns and common principles. Moreover, mutual learning and agreed practices are needed to develop joint solutions to societal problems and opportunities, and to pre-empt possible public value failures of future innovation.
2. Gender equality
Engagement means that all actors – women and men – are on board. The under-representation of women must be addressed. Research institutions, in particular their human resources management, need to be modernized. The gender dimension must be integrated in research and innovation content.
3. Science education
Europe must not only increase its number of researchers, it also needs to enhance the current education process to better equip future researchers and other societal actors with the necessary knowledge and tools to fully participate and take responsibility in the research and innovation process. There is an urgent need to boost the interest of children and youth in mathematics, science and technology, so they can become the researchers of tomorrow, and contribute to a scientifically-literate society. Creative thinking calls for science education as a means to make change happen.
4. Open access
In order to be responsible, research and innovation must be both transparent and accessible. This means giving free online access to the results of publicly-funded research (publications and data). This will boost innovation and further increase the use of scientific results by all societal actors.
5. Ethics
European society is based on shared values. In order to adequately respond to societal challenges, research and innovation must respect fundamental rights and the highest ethical standards. Beyond the mandatory legal aspects, this aims to ensure increased societal relevance and acceptability of research and innovation outcomes. Ethics should not be perceived as a constraint to research and innovation, but rather as a way of ensuring high quality results.
6. Governance
Policymakers also have a responsibility to prevent harmful or unethical developments in research and innovation. Through this key we will develop harmonious models for Responsible Research and Innovation that integrate public engagement, gender equality, science education, open access and ethics.

Using the six key issues gives the project a solid base to discuss how the research that is being introduced to the students. In Table 2 the six dimensions of RRI are explained a bit further.

The project IRRESISTIBLE is the result of a proposal that was accepted within the FP-7 program of the EU under number 612367. The proposal was made in response to call SIS.2013.2.2.1. [6]:

> *Area 5.2.2.1. Supporting formal and informal science education in schools as well as through science centers and museums and other relevant means.*
>
> *SiS.2013.2.2.1-1: Raising youth awareness to Responsible Research and Innovation through Inquiry Based Science Education*

Within the project IRRESISTIBLE activities are designed that foster the involvement of students and the public in the process of responsible research and innovation. The project raises awareness about RRI in two ways:

- Increasing content knowledge about research by bringing topics of cutting edge research into the program
- Fostering a discussion among the students regarding RRI issues about the topics that are introduced.

In these activities both formal and informal learning environments play an important role. The project functions within the field of chemistry education and tries to bridge the gap between research and secondary schools. By having the students make an exhibition about their projects which are exhibited in science centers, the project also involves the general public.

The development of the material

Within the project Community of Learners (CoL) have been formed to develop educational materials [7]. Both in the Netherlands in the development of 'Nieuwe Scheikunde' [8] as well as in Germany in 'Chemie in Kontext' [9] these communities have been used and are still used in the development of new material.

Within the CoL, experts from scientific research, science education research, science centers and teachers are brought together. When possible someone from industry was included as well. Together they worked on the development of new materials.

Inquiry based science education as well as context oriented chemistry education has been developed and worked on during the past 10 years [8, 10, 11]. In this project, the partners from 10 countries chose to use the 5 E method developed by Roger Bybee [12] as a framework for the modules to be developed. An extra step was added to extend it to 6E in which the students were asked to make an exhibit in which they demonstrated both the science they learned as well as the RRI-aspects the discussed. These exhibits were exhibited by the science centers that were part of the project.

Results

One of the important issues in working on grand challenges is the need for new scientists. Science education plays an important role in getting students interested in science. In this project, we identified topics from recent research, focusing on fields of the grand challenges. This has to be reworked to be able to bring it into a chemistry classroom. It has to be done in such a way that students can understand the scientific questions raised. They should also be able to discuss and form an opinion about the relevant RRI-issues. In Table 3 the titles of the modules developed by each partner are given. From the titles the field the modules cover can be derived. All modules have a similar set up and can be used directly by teachers. They are focused either on lower secondary school or higher secondary school. In most cases formal and informal learning (in a science center) is combined.

All modules that were developed have included the 6E framework. The teachers in the CoL have tried out all modules in their own classrooms. The modules have been adapted using their experiences in the classroom.

Table 3: Produced modules, with science content.

Country	Title	Research subject
1. Portugal	Geo-engineering and climate control	Geo-engineering
	Evaluate earth health through polar regions	Polar eco systems
2. Finland	Atmosphere and climate change	Climate change
3. Turkey	Nano for health	Nanomaterials used in health issues
4. Poland	The catalytic properties of nanomaterials	Role of nano particles as catalyst
5. Netherlands	Carbohydrates in breastmilk	Specific carbohydrates
6. Romania	Solar energy and specific nanomaterial	Grätzel cells
7. Italy (Bologna)	Nanotechnology for solar energy	Grätzel Cells
	Nanotechnology for information by exploiting light/matter interaction	Luminescent nanosensors
Palermo	Energy sources	Grätzel cells
8. Israel	The RRI of perovskite based photovoltaic cells	Perovskite solar cells
9. Germany	Oceanography and climate change	Off shore wind energy
	Plastic, bane of the oceans	Plastic waste in oceans
10. Greece	Nanoscience applications	Several nano-applications like the lotus effect

The modules are available through the Irresistible website: http://www.irresistible-project.eu/index.php/nl/.

Implementation of RRI

The implementation of RRI in the modules has been done in different ways. In the modules of Israel, Turkey and Germany the students are given a specific role. Incorporated in the role-play are the different RRI aspects. In the Turkish module, the students are given the roles of member (doctor, nurse, patient, cook, cleaning staff, technician etc.) of a committee. A hospital is asking them whether or not the hospital should introduce towels etc treated with nano silver particles. They then investigate the properties of cotton treated with silver nanoparticles and finally by discussing the consequences of washing textile containing silver nanoparticles, they highlight the key aspects of RRI and come up with an advice.

Fig. 1: Example of perovskite solar cells used in windows (http://news.sciencemag.org/node/112358).

The main question in the Israeli module is whether the windows in the school should be replaced with Perovskite solar cells (Fig. 1).

In the German module a game has been developed in which the students play and that way learn about off shore wind energy. Since the Fujiyama disasters in Japan, Germany decided to invest heavily in wind energy.

In other modules the RRI dimensions were introduced during the 'Elaborate' step of the framework as a separate chapter (Fig. 2).

Fig. 2: Introduction of RRI in a chapter of a module.

Fig. 3: Students debating about propositions.

In some cases a debate was organized around specific propositions (Fig. 3). An example is: 'a company has the right to market their products all over the world' taken from the module about formula milk.

Students were then asked to apply the RRI dimensions to the scientific content they studied in the first part of the module. The students were asked to make an exhibit demonstrating the dimensions of RRI focused on the science content they learned about. These exhibits were taken to the science center involved in the project and displayed there. In Germany, a system for the exhibits was developed using a cupboard from 'Ikea' (Fig. 4).

The cupboard was designed by the students to illustrate the issues involved. In this case the module is about the differences between human milk and cow milk.

In other cases cartoons were used (Fig. 5). In Fig. 6 an overview of the exhibition in Greece shown.

Fig. 4: Use of an Ikea cupboard as base for an exhibit.

Fig. 5: Cartoons made to illustrate RRI – issues.

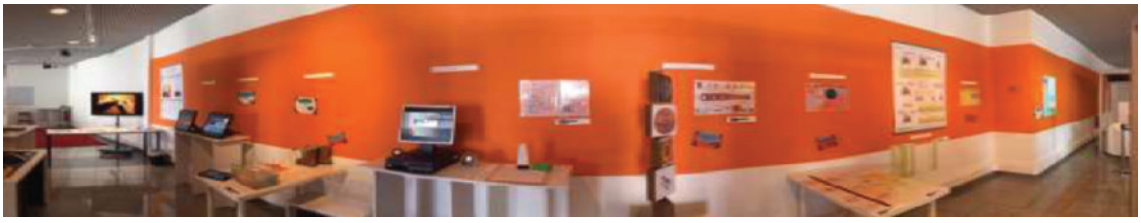

Fig. 6: Overview of exhibition in Greece.

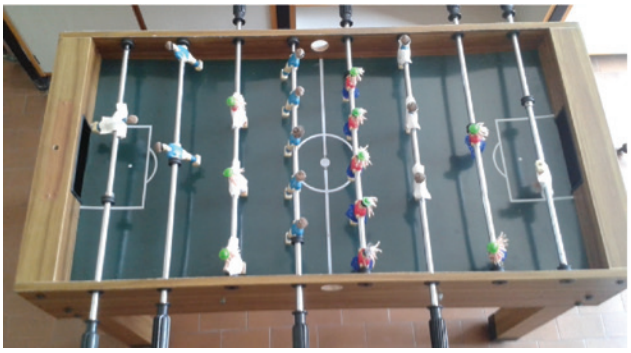

Fig. 7: Table football game adapted in Italy with male and female players.

Students are very creative in designing exhibits. By careful guidance by the experts from the science centers exhibitions are made that can actually be used within the science centers.

Students are able to use the advice they have received about exhibits in innovative ways. In Italy, for example a table football game was adapted to demonstrate principles of RRI (Fig. 7).

Conclusions and recommendations

Looking at the modules and more specifically at the exhibits that have been produced by the students it becomes clear that the project IRRESISTIBLE modules are able to introduce cutting edge science research into the secondary school classroom. In most cases this fits in with the national curriculum, while in other cases the material is extra-curricular.

Our experiences also show that students are very able to link the RRI dimensions to the science they have been studying. In Israel it has become more or less a verb: *'let's RRI this issue'*.

The student-curated exhibits are an important element in the modules when bringing together the science content and the RRI ideas. Designing the exhibits forces the students to think about the issues and come up with ways to demonstrate to the public the RRI dimensions of the field of research and/or innovation. They are also a way to involve parents, and more general public to the science introduced.

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